Reference Frame Working Group Technical Report

R. Ferland
Natural Resources Canada, Geodetic Survey Division
456-615 Booth Street, Ottawa, Ontario, Canada.
Tel: 1-613-995-4002; Fax: 1-613-995-3215.
e-mail: ferland@geod.nrcan.gc.ca;

Abstract

Natural Resources Canada's (NRCan) Geodetic Survey Division (GSD), on behalf of the International GPS Service (IGS) and its Reference Frame Working Group, combines a consistent set of station coordinates, velocities, Earth Rotation Parameters (ERP) and apparent geocenter to produce the IGS official station position/ERP solutions in the Software Independent Exchange (SINEX) format. The weekly combination includes solutions from the Analysis Centers (AC), while the Global Networks Associate Analysis Centers (GNAAC) provide quality control.

The weekly AC solutions include estimates of weekly station coordinates and daily ERPs. The ACs currently process weekly data from between 40 and 140 stations They also provide separately, satellite orbit and clock estimates as part of their daily products, which are independently but consistently combined by the IGS AC Coordinator to produce the IGS orbit/clock products. The weekly combined station coordinates are accumulated in a cumulative solution containing estimated station coordinates and velocities at a reference epoch.

This year activities also included the implementation of the IGS realization of ITRF2000. All the proposed additions/changes are in the Southern Hemisphere, with the main objective being to improve the reference frame (RF) station distribution. In South America, two new stations were added while two old ones were removed. Three other stations were also added; one on Ascension Island in the Atlantic Ocean, one on Diego Garcia Island in the Indian Ocean and one in Australia.

The group also participated to two IERS activities; namely, the definition of the SINEX version 2.0 and some analysis of the stability of ERP's. The objectives of the SINEX version 2.0 extensions were to accommodate the requirements of other techniques and the inclusion of the normal equations for multi-techniques combinations.

Introduction

Station coordinates and velocities, Earth Rotation Parameters (ERP) and geocenter products are generated within the Reference Frame Working Group (RFWG) (Kouba et. al., 1998). These products also influence the combination of the GPS satellite ephemeredes and clock products. Since February 27, 2000 (GPS Week 1051), the AC coordinator aligns the orbit products to the weekly SINEX cumulative combinations, thus ensuring IGS products consistency. The weekly SINEX combination is available within 12 days (Thursday) of the end of each GPS week. The ERPs are included in the weekly SINEX combination along with the station coordinates. The combination uses all the available covariance information.

The IGS RFWG contribution to the International Terrestrial Reference Frame (ITRF) can be subdivided into two main initiatives: first, the participation of ACs and IGS in the ITRF solutions and second, the realization and dissemination of ITRF. The IGS RFWG contribution to ITRF2000 was provided in November 2000 and included 167 stations (Ferland, R. 2002). For the period of GPS weeks 0837 (January 21, 1996) and 0977 (October 3, 1998), the weekly combined solutions from JPL, MIT and NCL Global Associates Analysis Centers (GNAAC) were used in the cumulative solution. Since GPS week 0978 (October 4, 1998), the seven ACs (COD, EMR, ESA, GFZ, JPL, NGS and SIO) are used in the combination, while the GNAACs are used to control the quality of the weekly combination (Table 1). The IGS contribution took the form of a cumulative solution that included data between GPS weeks 0837 and 1088 (January 21, 1996 – November 18, 2000). The IGS realization of ITRF is accomplished with a subset of stations of the IGS network. For the realization of ITRF2000, 54 high quality stations were selected. (Kouba et al., 1998). The accessibility to the reference frame is facilitated through the combined “IGS core products” of station coordinates, the Earth Rotation Parameters and/or the precise orbits, and the satellites/stations clock solutions. The IGS Reference frame realization of ITRF can be accessed, by GPS users, with their precise code and phase observations. Data used to realize an IGS ITRF will also be subsequently contributed to the IERS combination process to generate ITRF at future epochs.

Table 1. IGS Analysis and Associate Analysis Centers

IGS Analysis Centers (AC)	
CODE	Center for Orbit Determination in Europe, AIUB, Switzerland
ESOC	European Space Operations Center, ESA, Germany
GFZ	GeoForschungsZentrum, Germany
JPL	Jet Propulsion Laboratory, USA
NOAA	National Oceanic and Atmospheric Administration / NGS, USA
NRCan	Natural Resources Canada, Canada
SIO	Scripps Institution of Oceanography, USA
IGS Global Network Associate Analysis Centers (GNAAC)	
NCL	University of Newcastle-upon-Tyne
MIT	Massachusetts Institute of Technology
JPL	FLINN Analysis Center Jet Propulsion Laboratory (up to 00/09/09)

Weekly SINEX combination

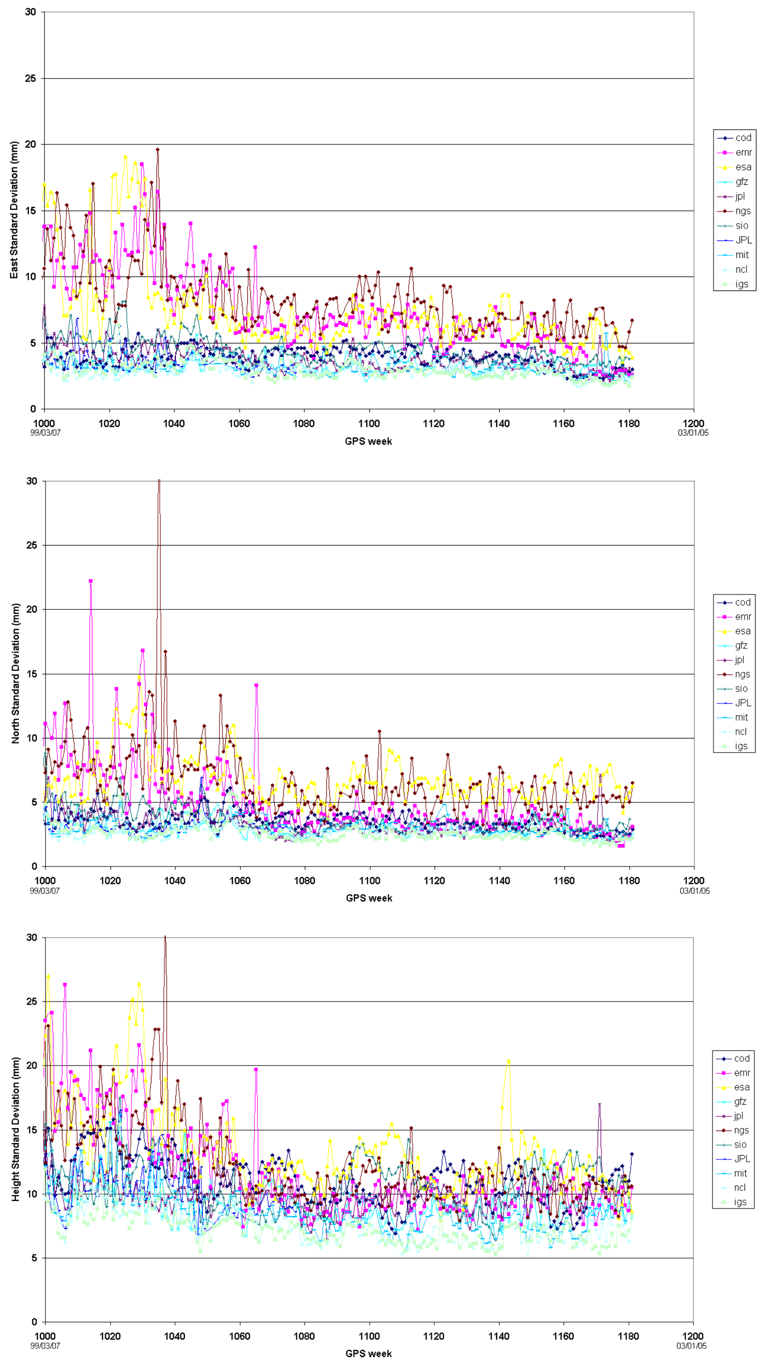

Figure 1. North, east and height stations residuals standard deviation between the AC, GNAAC and IGS weekly solutions and the IGS cumulative solution.

The AC solutions are combined using the least-squares technique. All the available covariance information between the station coordinates within each AC solution is used. Since GPS week 1013 (June 6, 1999) the weekly combination also includes daily ERP (pole position and rate, calibrated length of day (Mireault et al. 1999)) and since GPS week 0978 (October 4, 1998) weekly apparent geocenter estimates. The cumulative combination is updated every week with the latest weekly combination. The alignment of the weekly and cumulative solution is done using a set of reference frame stations (see the next section). Since GPS week 1000 (March 7, 1999), weekly comparisons between the IGS weekly and the cumulative solution show standard deviations of about 3 mm horizontally and 6-8 mm vertically. Figure 1 shows the standard deviation of the weekly station coordinates residuals between the ACs GNAACs and IGS with respect to the IGS cumulative solution. Gradual improvement is apparent especially in the

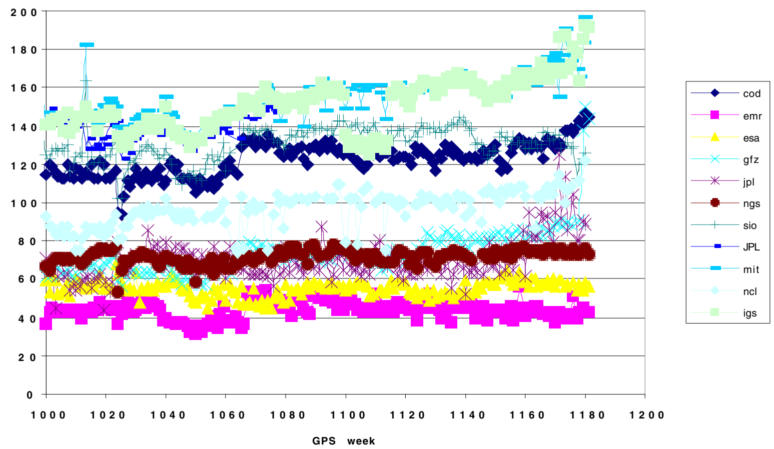

Figure 2. Number of Stations in the Weekly AC, GNAAC & IGS SINEX Solutions

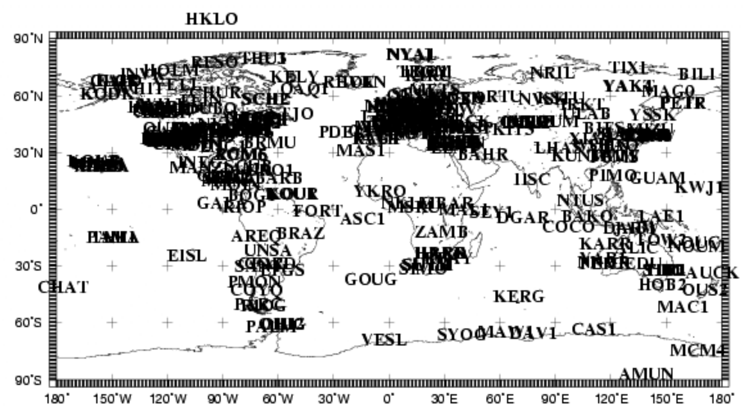

Figure 3. Stations in the “extended” Cumulative Solution

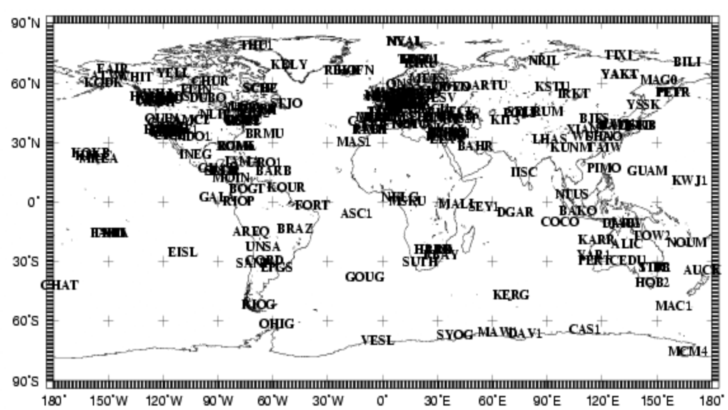

Figure 4. Stations available in the Cumulative Solution

height component. The bandwidth of the deviations is also decreasing, indicating a better level of agreement between the various solutions.

Equipment, local environment and processing changes are the causes for a number of discontinuities in the station coordinate time series. Those are also visible in the residual time series after linear. Comparisons done in the past between the weekly and cumulative solution statistics have indicated that non-random effects account for up to 30% of the residuals signature. Discontinuities, which tend to affect mainly the height, are generally caused by either blunders, equipment or processing changes.

The number of operational stations is steadily increasing. The number of stations processed and submitted by the ACs is also increasing. In the IGS weekly combination, the

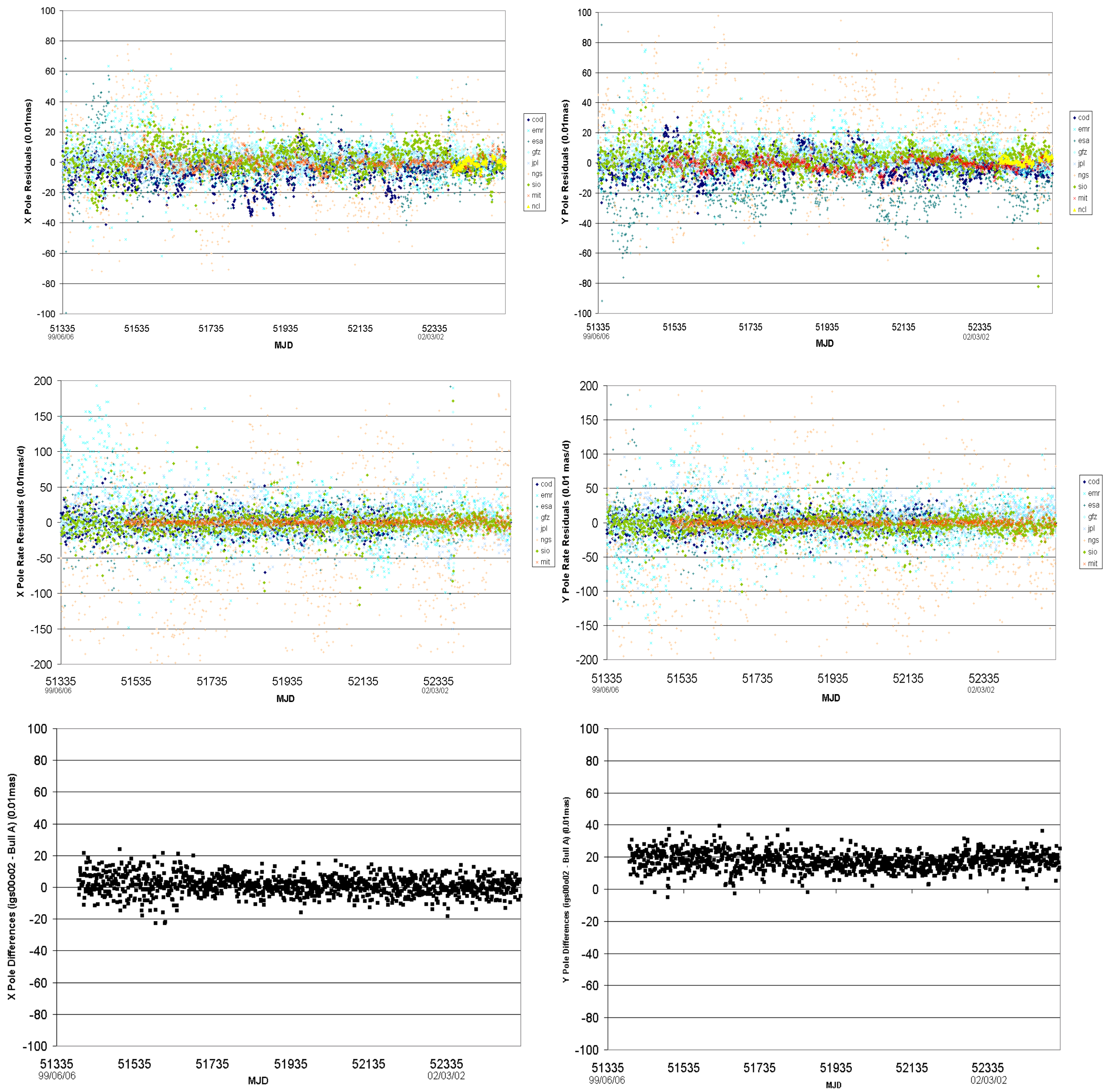

Figure 5. Daily X Pole, Y Pole (top), X Pole Rate, Y Pole Rate (middle) differences between the combined solution “igs00p02” and the AC & GNAAC estimates. Daily X Pole, Y Pole (bottom) differences between the combined solution “igs00p02” and the Bulletin A.

number of stations increases on average by one station per month. Due to ongoing changes in the stations selected by the ACs in their processing, the number of stations in the cumulative solution increases at rate of almost two stations per month. Figure 2 shows the evolution in the number of stations included in the weekly ACs, GNAACs and IGS combined SINEX solutions. The ACs currently process about 40 and 140 stations weekly. The weekly combined solution now exceeds 180 stations. All the weekly station coordinate estimates provided by the AC are currently combined and made available. The "extended" cumulative solution generated from these weekly combinations currently includes over 340 stations (Figure 3). Of those, 215 stations with reliable information are included in the IGS SINEX Combination (Figure 4). Cumulative solutions for over 120 stations are not yet releases for the following reasons: they are missing essential info such as dome #, site logs; they cover a short time span (e.g. < ~1 year) which prevent reliable velocity estimation; or they are located in geographical areas that are already well covered (e.g. North America and Europe).

The daily ERPs are combined in the weekly SINEX solution along with the station coordinates by making use of all covariance information. The best AC pole positions and rates are consistent at the 0.05-0.10mas (0.10–0.20mas/d), while the calibrated LOD are consistent at 20-30us. Figure 5 show the daily residuals time series for the X and Y pole (Top) and their rates (Middle) between the combined solution "igs00p02" and the AC/GNAAC. The bottom portion shows the daily difference between the combined solution and Bulletin A. Note that the IGS combined solution and the Bulletin A are not independent, since the AC solutions contribute significantly to Bulletin A. The Bulletin A daily estimates were linearly interpolated to match the corresponding epochs of the IGS combined values. Small differences between the AC combined pole and pole rates are due to differences in processing strategy (e.g.: different weighting and rejection criterion). Independent daily ERPs using a different weighting are also estimated as part of the final GPS orbit combination process "igs95p02". Comparison between the igs00p02 and igs95p02 show no significant average difference between them, and a noise level of about 0.06mas (0.10mas/d) which is similar to the differences with respect to Bulletin A (bias removed) (0.07mas & 0.17mas/d). The GNAAC NCL analysis center has also started combining the pole positions as well as the LOD.

Implementation of ITRF2000

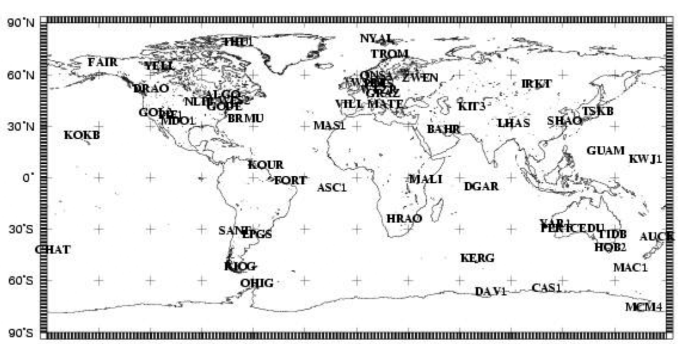

Figure 6. IGS00 Reference Frame Stations

ITRF2000 (Altamimi, 2001) was made available in the spring of 2001. The ITRF2000 combines solutions from a number of space techniques including Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Doppler Orbitography by Radio-positioning Integrated on Satellite (DORIS) and GPS. The IGS solution was part of a group of about 20 global solutions used for the realization of ITRF2000. Five other GPS (AC) global solutions were also submitted as well as six densification solutions. The IGS cumulative solution submitted to ITRF, was an edited solution extracted from IGS00P46.snx. The solution included the GPS weeks 0837 to 1088. The ACs/GNAACs (COD, GFZ, JPL, NGS, NCL) also provided their global cumulative solutions that are also included in ITRF2000. The "IGS00" realization of ITRF2000 was extracted from the cumulative solution "IGS01P37.snx" GPS week 1131 (September 9-15, 2001). After an analysis of the performance of the reference frame stations used for IGS97, it was decided to remove two stations and add five new ones. The station BRAZ was removed because it had been providing timely data for only a few weeks during the previous 12 months. Station AREQ was removed due to an earthquake that caused a significant discontinuity on June 23, 2001 ($\Delta\varphi$= -34cm, $\Delta\lambda$ = -47cm, Δh= - 2cm). In an attempt to compensate for removal of BRAZ and AREQ from the reference frame stations list, stations LPGS and RIOG, both in Argentina, were added. Both stations were contributing quality and timely data; their coordinates time series were also stable. RIOG was also collocated with DORIS. Stations at ASC1 (Ascension Island) and DGAR (Diego Garcia Island) were also added. These stations are also contributing to strengthen the reference frame network around Africa. Alternatives on the African continent were considered (e. g.: NKLG& YKRO), but, their track record was considered too short for reliable velocity estimate. One more station (CEDU) was added in Australia. See Figure 6 for a map of the IGS00 Reference Frame stations.

Table 2. Transformation Parameters from IGS (ITRF97) to IGS (ITRF2000) at December 02, 2001

At December 02, 2001	Translations			Rotations			Scale
	TX (mm)	TY (mm)	TZ (mm)	RX (mas)	RY (mas)	RZ (mas)	S (ppb)
(1 sigma)	-4.5 (4.1)	-2.4 (5.0)	26.0 (7.5)	-0.024 (0.092)	-0.004 (0.099)	-0.159 (0.076)	-1.451 (0.27)
Rate (/y) (1 sigma)	0.4 (1.7)	0.8 (1.9)	1.6 (2.8)	0.003 (0.038)	-0.001 (0.040)	-0.030 (0.034)	-0.03 (0.12)

Although, the ITRF97 and ITRF2000 are supposed to be aligned, there are some small transformation parameters between their IGS realizations mainly due to network effects. Based on the 49 common stations between the two IGS realizations of ITRF, the estimated transformation parameters (3 translations, 3 rotations, 1 scale and their respective rates) from IGS (ITRF97) to IGS (ITRF2000) are given in Table 2. The change from IGS97 to IGS00 was made on GPS week 1143 (December 2, 2001).

As part of an IERS analysis campaign, several strategies to realize ITRF2000 were analyzed to evaluate their effects on the ERP's. The strategies included different sub-networks and weighting schemes. The strategies were tested on two years of IGS weekly SINEX combinations. Comparisons have shown that the impact of the different strategies on the ERP's never exceeded 0.03 mas.

The differences between the ITRF2000 and IGS00 reference frame stations have position RMS of (0.5mm, 0.7mm, 2.5mm) and velocity RMS of (0.6mm/y, 0.8mm/y, 1.7mm/y) in the north, east and height directions.

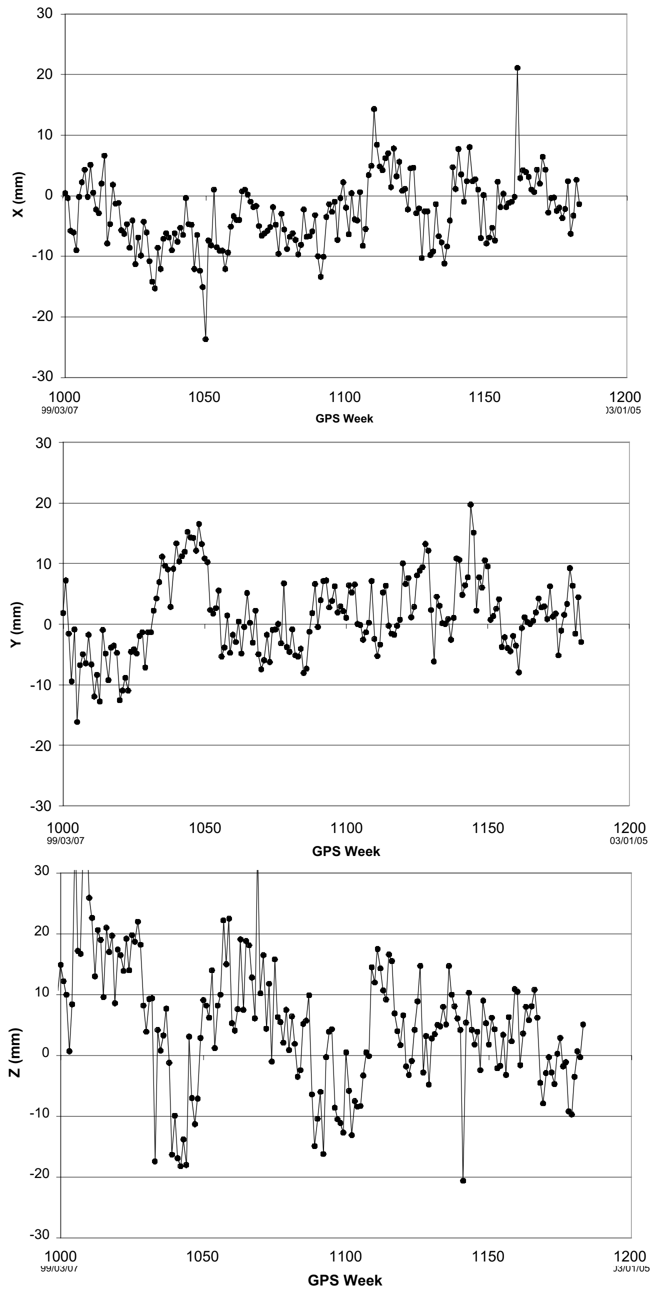

Figure 7. Apparent Geocenter Weekly estimates with respect to current IGS realization of ITRF2000.

Figure 7 shows the weekly apparent geocenter position. Linear regression analysis on those time series indicates that there may still be some small drift in all 3 components of the apparent geocenter (2.0 +-0.8 mm/y, 1.5 +-0.9mm/y, -3.7 +- 1.4 mm/y).

Summary

The IGS cumulative solution now contains about 340 stations among which 215 are made available weekly. This is considered sufficient for ITRF densification purposes. The IGS realization of ITRF uses a subset of the IGS cumulative solution. This improves the internal stability and consistency of the weekly product alignment. Tests with different realizations of ITRF2000 have indicated that the effect on the ERP’s never exceeded 0.03mas. The use of the 7 ACs and the 2 GNAACs provide significant redundancy and robustness to the analysis. The analysis has also shown that station statistics have a gradually improved over the years. The weekly apparent geocenter estimates show improved agreement with the IGS realization of ITRF2000 origin compared to the IGS realization of ITRF97.

Acknowledgements

A large number of agencies contribute to IGS. Among them are the agencies responsible for the installation and maintenance of the tracking stations, the regional and global data centers in addition to the ACs and GNAACs already mentioned. A complete list of contributors can be found at the IGS web site (http://igscb.jpl.nasa.gov/). Also thanks to J. Kouba and P. Heroux for reviewing this report.

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